Jet energy scale and resolution

in the DØ calorimeter

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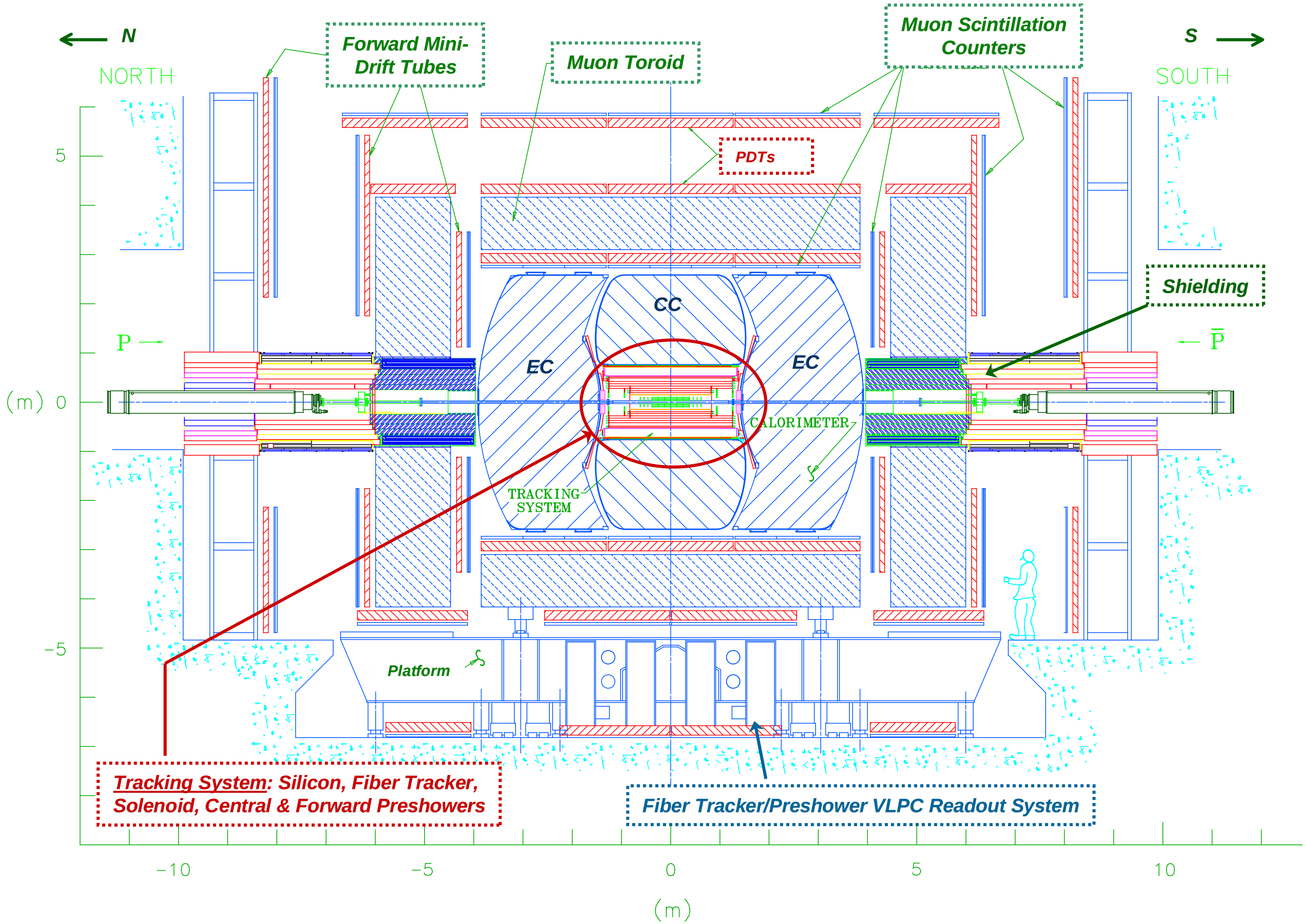
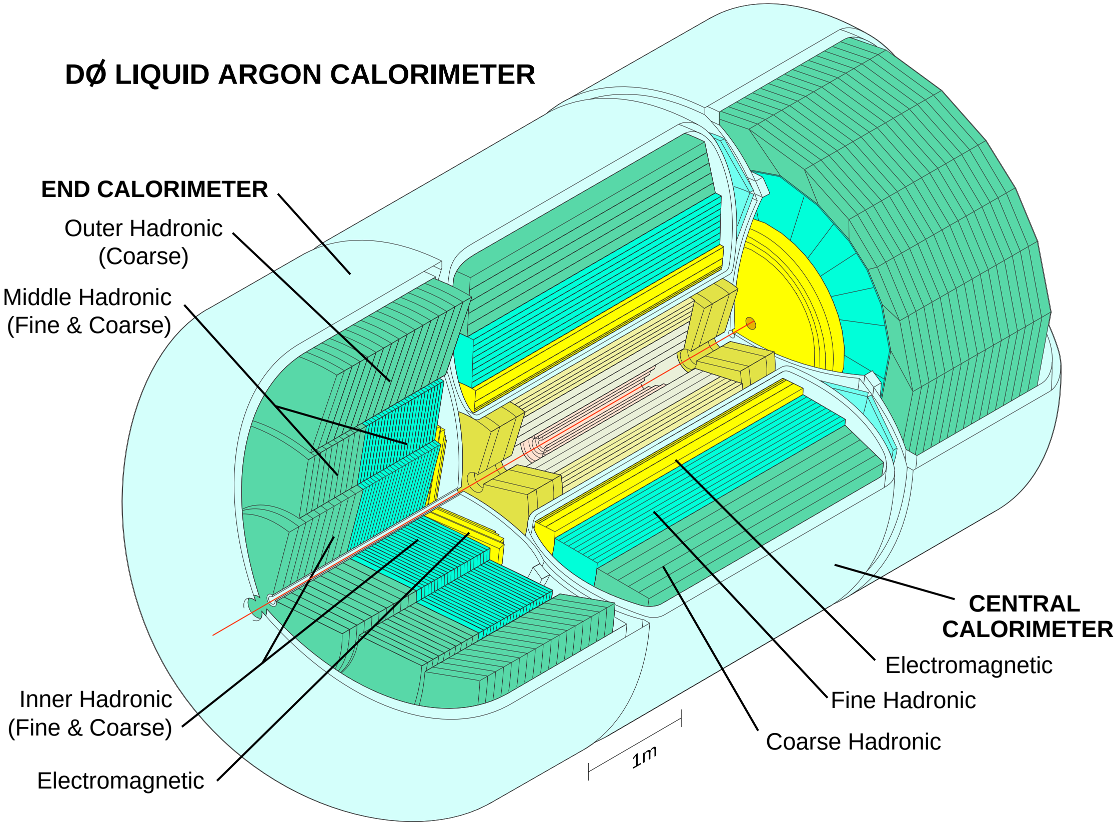
Run II upgrade of the DØ detector



Calorimeter



- uniform and hermetic
  - coverage up to $|\eta| < 4.2$
- nearly compensating
- fine segmentation
  - $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

    (3rd EM layer: 0.05×0.05)
- particle energy resolution

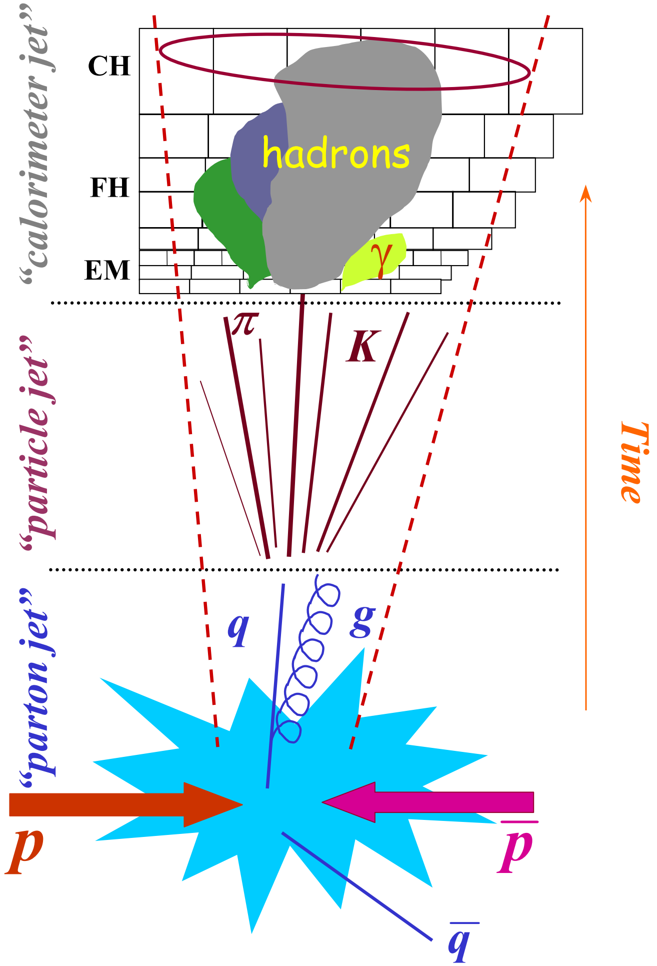
  $$e \ : \ \frac{\sigma}{E} = \frac{15\%}{\sqrt{E}} \oplus 0.3\%$$

  $$\pi \ : \ \frac{\sigma}{E} = \frac{45\%}{\sqrt{E}} \oplus 4\%$$

Run II upgrade

- shorter time between bunch crossings (396 ns) $\Rightarrow$ faster trigger and readout electronics
- more material in front of calorimeter (magnet, new tracker) $\Rightarrow$ new preshower detector

Jets



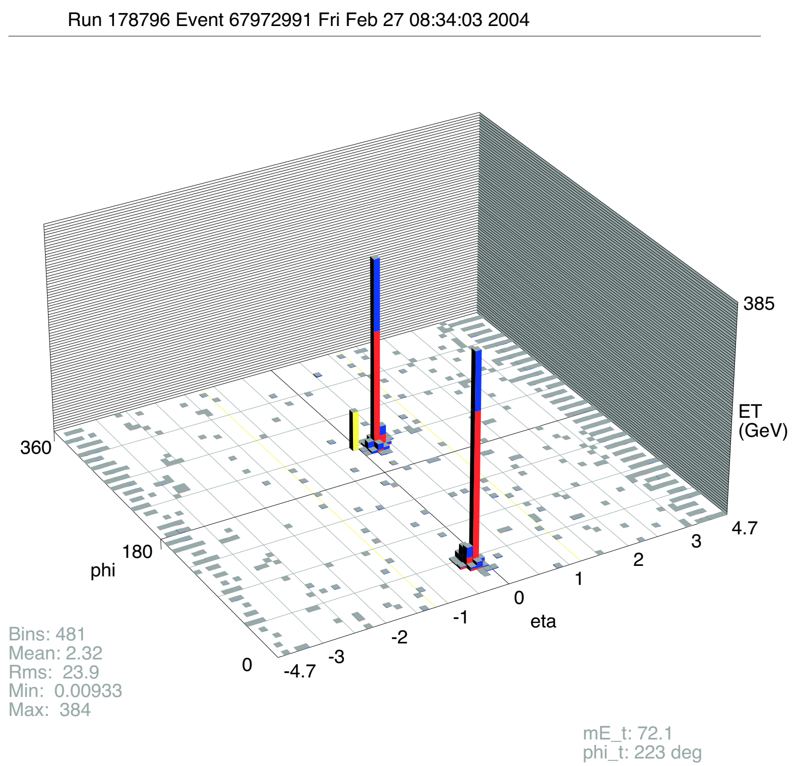
- ▷ calorimeter jet
  - calorimeter - main tool for jet measurement
  - jet is a collection of towers
  - geometrical definition (cone algorithms)
  - pQCD motivated algorithms (k_T)
- ▷ particle jet
  - after hadronization
  - a spread of particles running roughly in the same direction as the parton
- ▷ parton jet
  - parton hard scattering
  - parton showers

Run II cone algorithm

- a collection of towers within a given cone $R = \sqrt{\Delta^2\varphi + \Delta^2\eta}$
  - φ is the azimuthal angle
  - pseudorapidity η is related to the polar angle ϑ : $\eta = -\log\tan(\vartheta/2)$
- recombination scheme - E-scheme

$$E_{jet} = \sum_{towers} E_i \,, \quad \vec{p}_{jet} = \sum_{towers} \vec{p}_i$$

- cone axis - stable directions
  - iterative procedure starts only from seeds above some threshold
  - using midpoints as an additional starting seeds
- splitting and merging overlapping jets
- accept only jets with $E_T > 8\,\mathrm{GeV}$



Jet energy scale

correction of the jet energy measured on the detector level to the jet energy on the particle level

$$E^{jet}_{ptcl} = \frac{E^{jet}_{det} - \mathcal{O}}{R_{jet}\, S}$$

Offset $(\mathcal{O})$ - energy not associated with the hard interaction (U noise, pile-up from previous crossings, additional $p\bar{p}$ interactions)

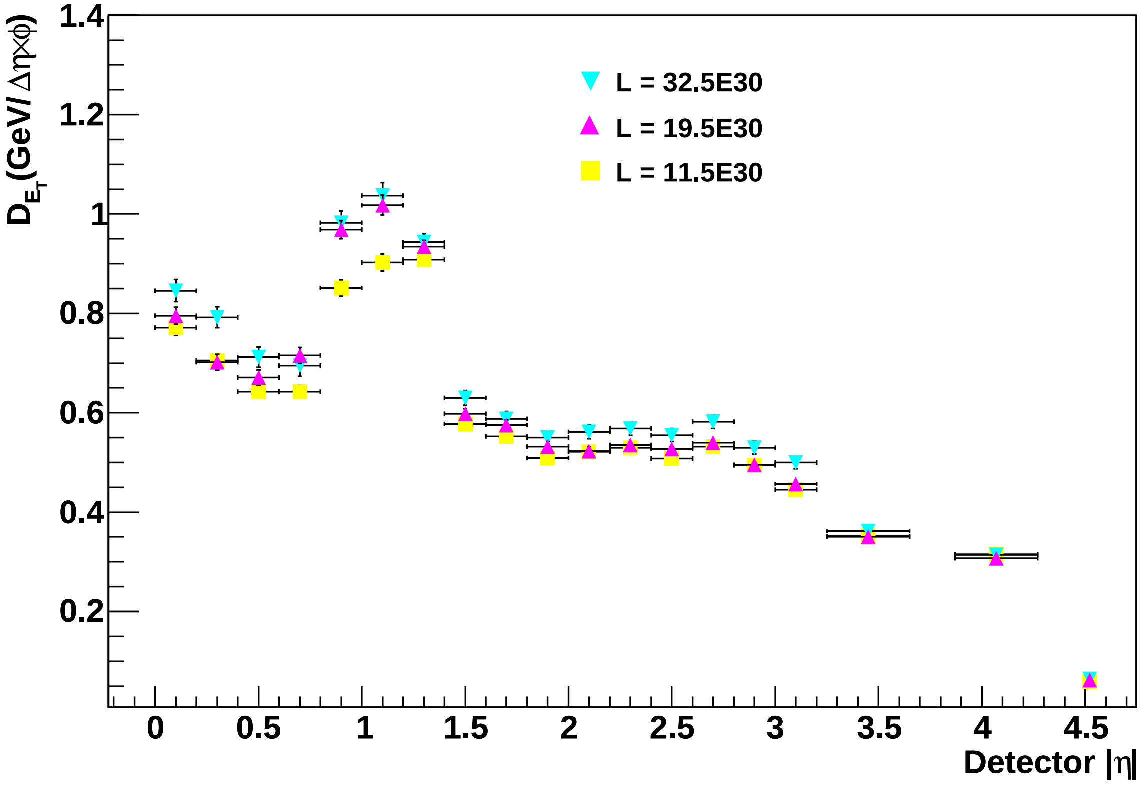
Response (R_{jet})

- calorimeter response to the jet
- EM part calibrated on $Z \rightarrow ee$ mass peak
- measured from E_T balance in $\gamma +$ jet events

Showering (S) - losses due to showering the energy in the calorimeter out of the jet cone

Offset - $\mathcal{O}(\mathcal{L}, \eta, R_{cone})$

Offset $(\mathcal{O})$ - energy not associated with the hard interaction (U noise, pile-up from previous crossings, additional $p\bar{p}$ interactions)



- average tower E_T density

$$\mathcal{D}_{E_T} = \frac{\sum_\phi E_T(\eta)}{2\pi\, \Delta\eta\, N_{events}}$$

- $\mathcal{D}_{E_T}$ measured in two different samples
  - zero bias (accelerator clock)
  - minimum bias (inelastic scattering)

- offset for $R = 0.7$ cone is about $1\,$GeV

Jet response

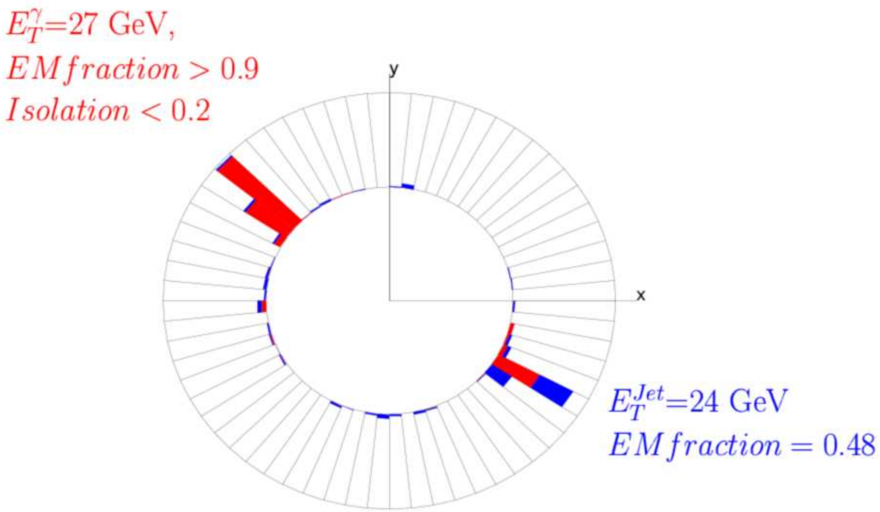
- deposited energy is different from the measured one
  - calorimeter is not perfectly compensated : $\frac{e}{\pi} \sim 1.05$ for $E > 30$ GeV
  - dead material, module-to-module fluctuations, ...

Missing E_T projection method

- jet response determined from the p_T imbalance in γ+jet events

$$\vec{E}_{T\gamma} + \vec{E}_{Trecoil} = 0 \qquad \text{(ideal)}$$

$$R_\gamma \vec{E}_{T\gamma} + R_{recoil} \vec{E}_{Trecoil} = -\vec{\not{E}}_T \qquad \text{(real)}$$



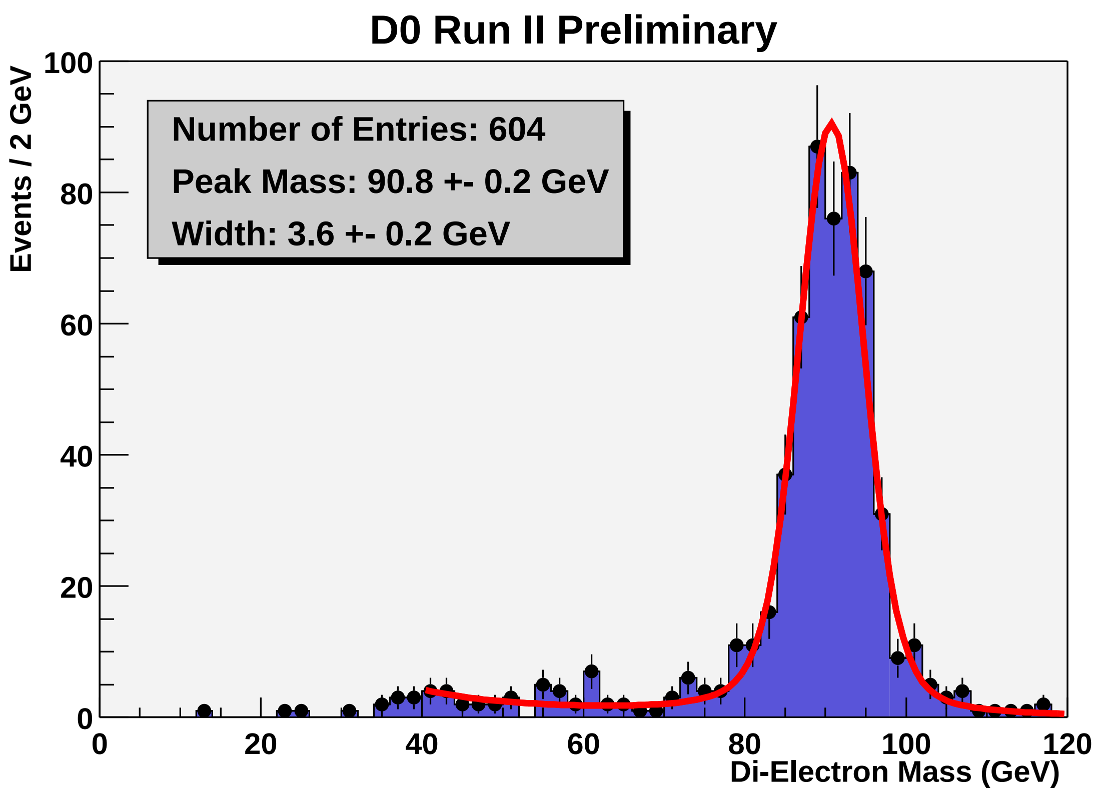
- after EM energy calibration from the $Z \to ee$ mass peak ($R_\gamma = 1$)

$$R_{recoil} = 1 + \frac{\vec{n}_{T\gamma} \cdot \vec{\not{E}}_T}{E_{T\gamma}}$$

- select nice, back-to-back, γ+jet events

$$R_{jet} = R_{recoil}$$

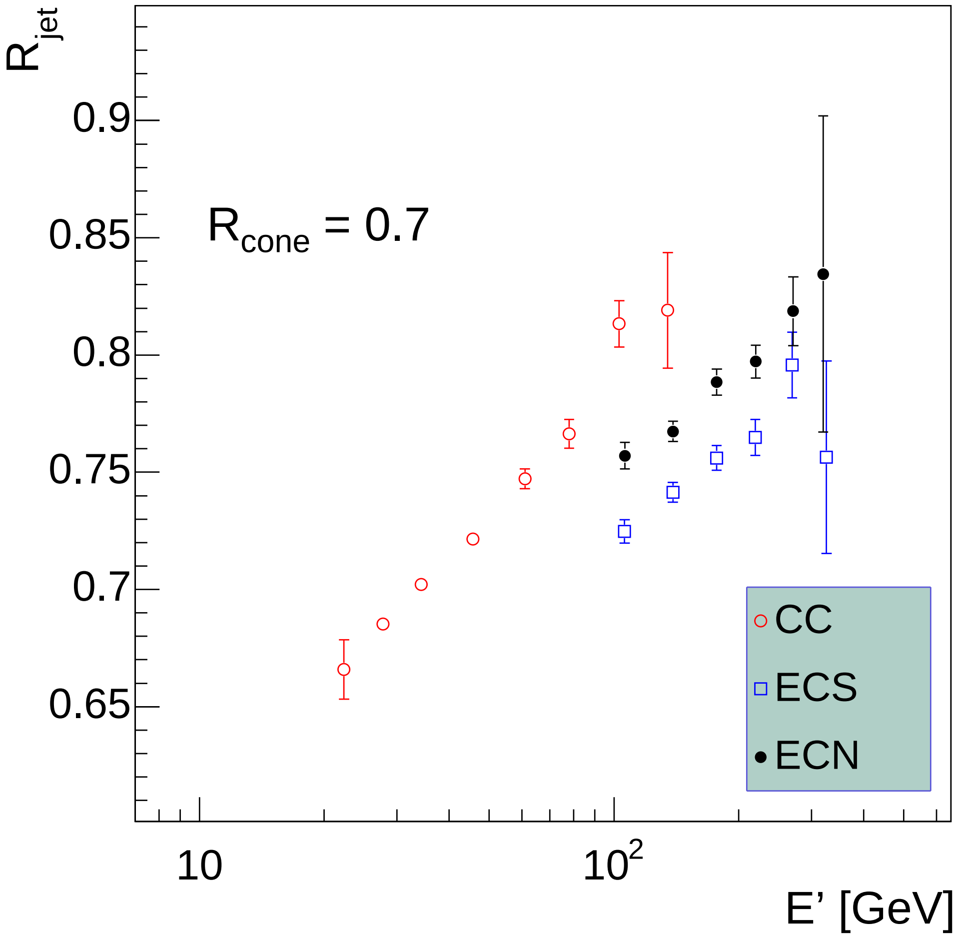
EM scale



- determined from $Z \to e^+e^-$ mass peak

- typical size of EM scale is between 1-5%

Response in central and forward cryostats



Events are placed in various E' bins

$$E' = E_{T\gamma} \cosh(\eta_{jet})$$

- photon energy and jet direction are well measured quantities
- smearing effects are minimazed

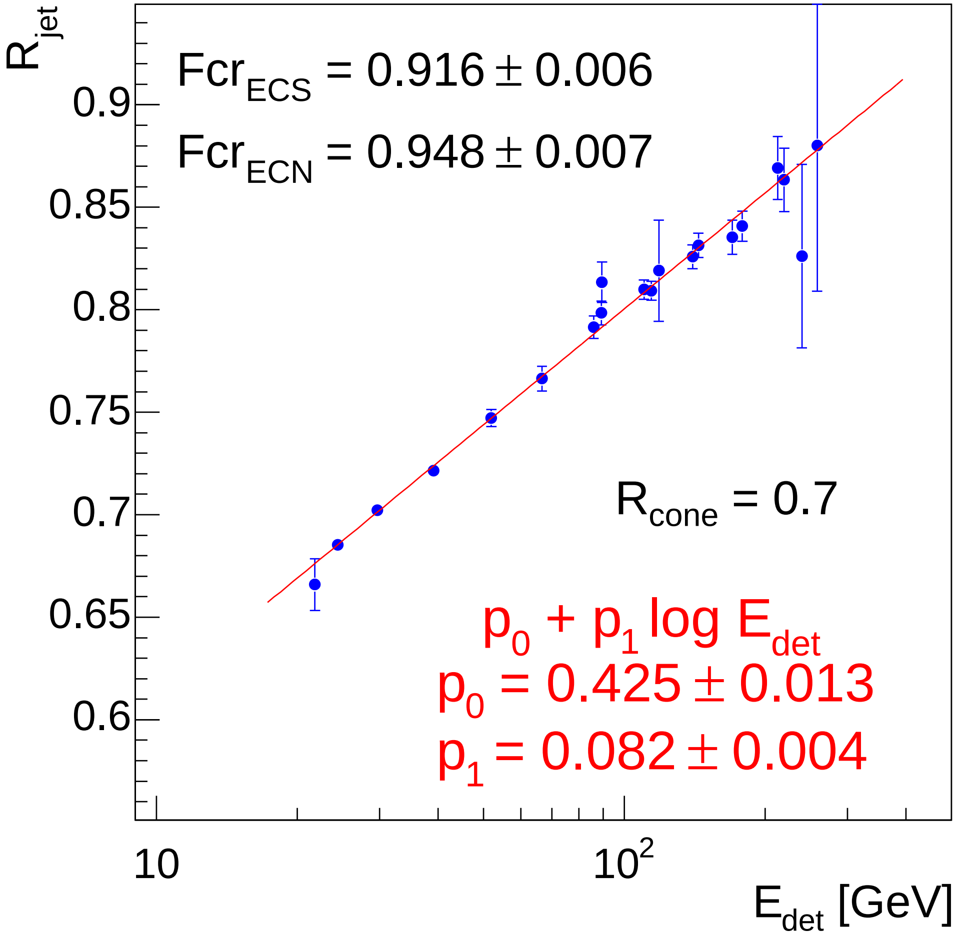
CC - jet in the central cryostat

ECS - jet in the south end-cap

ECN - jet in the north end-cap

- different response in cryostats $\Rightarrow$ cryostat factors

Response



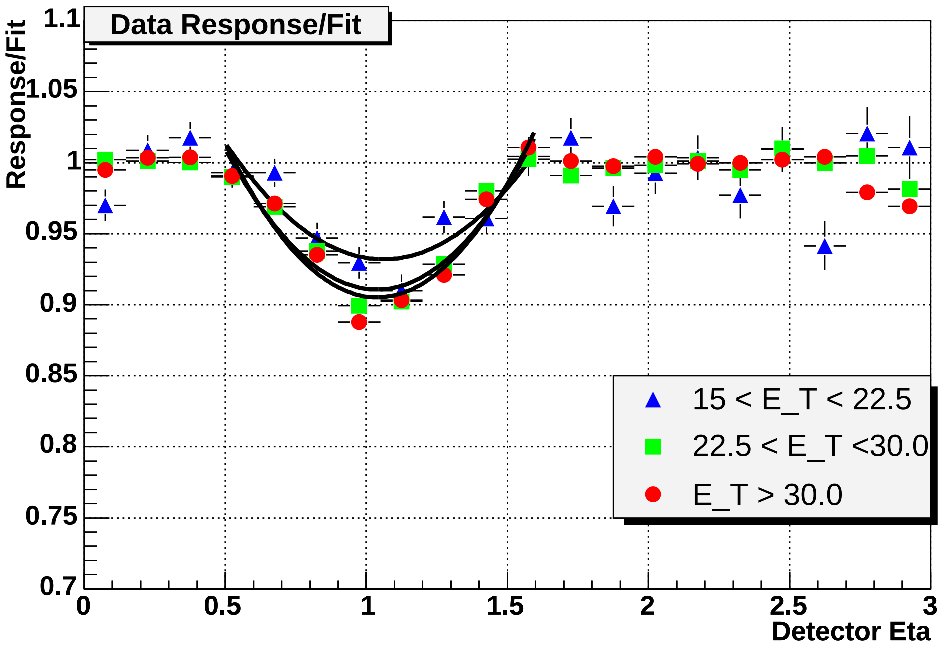
- mapping from E' to measured jet energies E_{det}
- statistical error

  $< 1\%$ for $20 - 250$ GeV
- systematic error

  $\sim 4 - 5\%$ for $20 - 250$ GeV
  - variation of selection cuts
  - closure tests on MC and different data samples $(Z + jet)$

- for jets in the end-caps, corresponding cryostat factor is applied
- special treatment in the inter-cryostat region (ICR)

Response in ICR



- η dependence studied in γ+jet events
- expect log-linear dependence in uniform detector

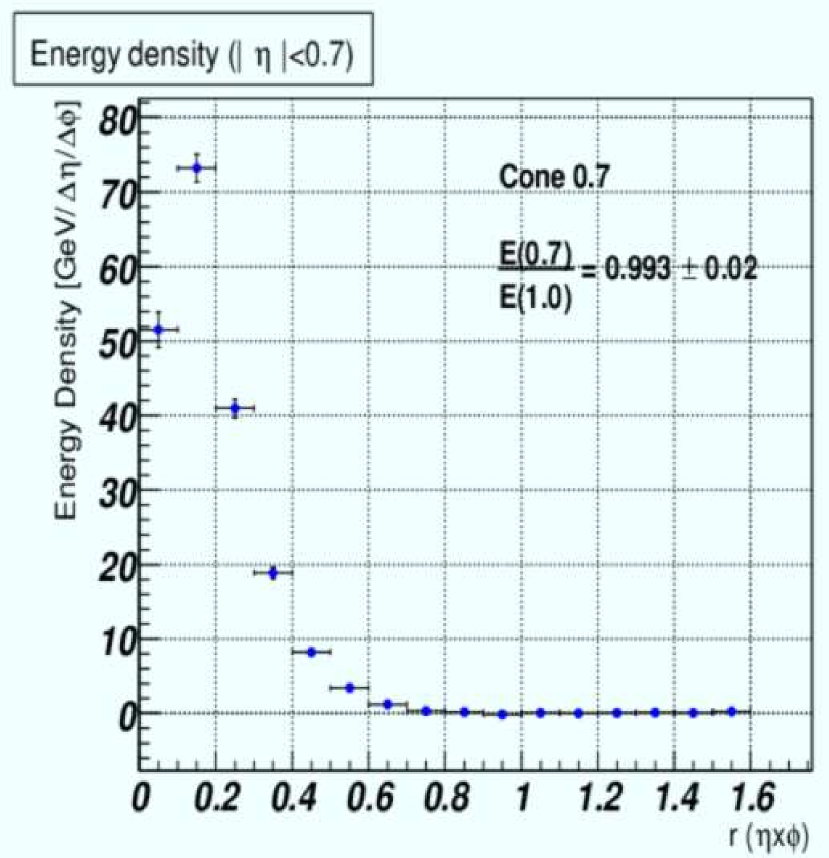
$$R_{jet}(\eta) = a + b \log[\cosh(\eta)]$$

ICR correction

- obtained from the response deviation from the log-linear dependence
- applied in the region $0.5 < |\eta| < 1.5$

Showering - $S(\eta, R_{cone})$

Showering (S) - losses due to showering the energy in the calorimeter out of the jet cone



Method

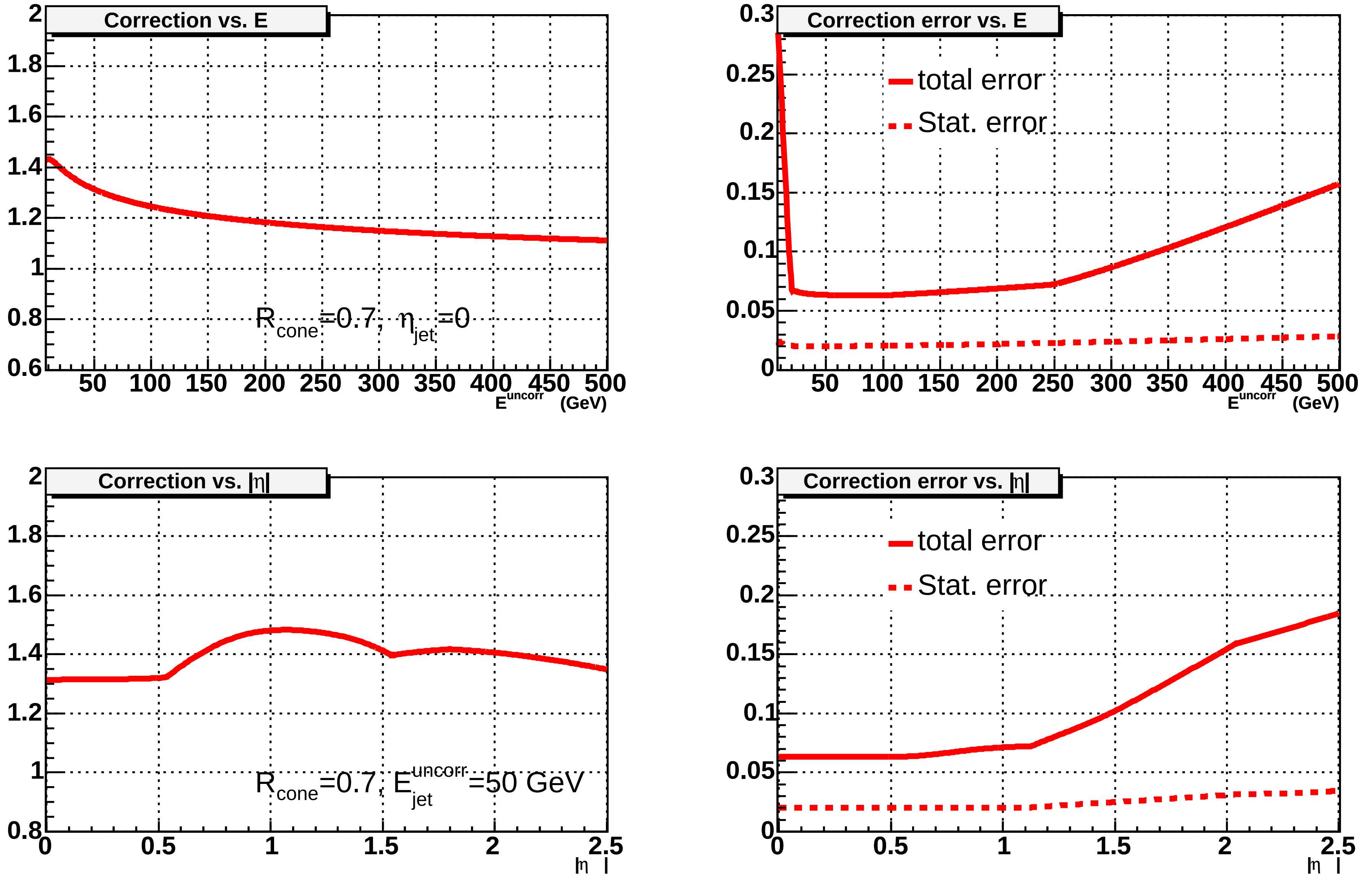
- study energy flow as a function of distance from the jet axis

$$r = \sqrt{(\eta - \eta_{jet})^2 + (\phi - \phi_{jet})^2}$$

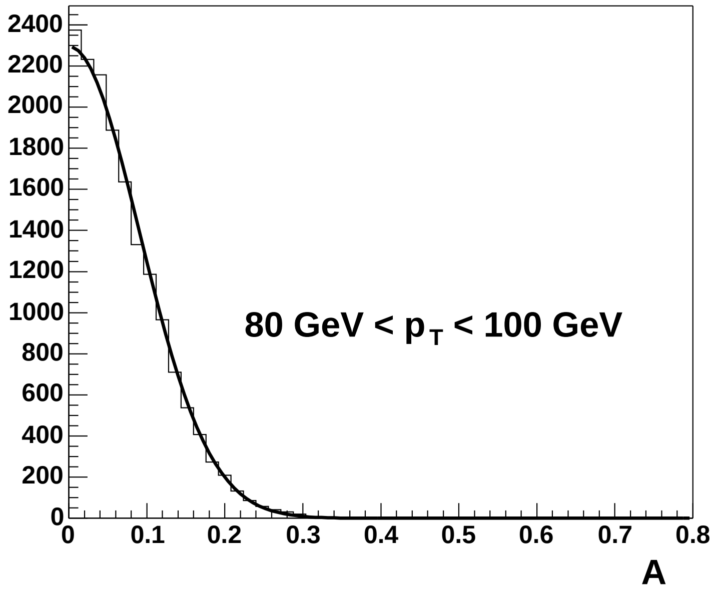
	$R = 0.7$	$R = 0.5$
Central	0.99	0.92
ICR	0.96	0.89
Forward	0.94	0.85

- 5% systematic error

Overall jet energy correction



Jet p_T resolution



- dijet events for $E > 50$ GeV
  - select nice back-to-back dijet events
  - p_T asymmetry

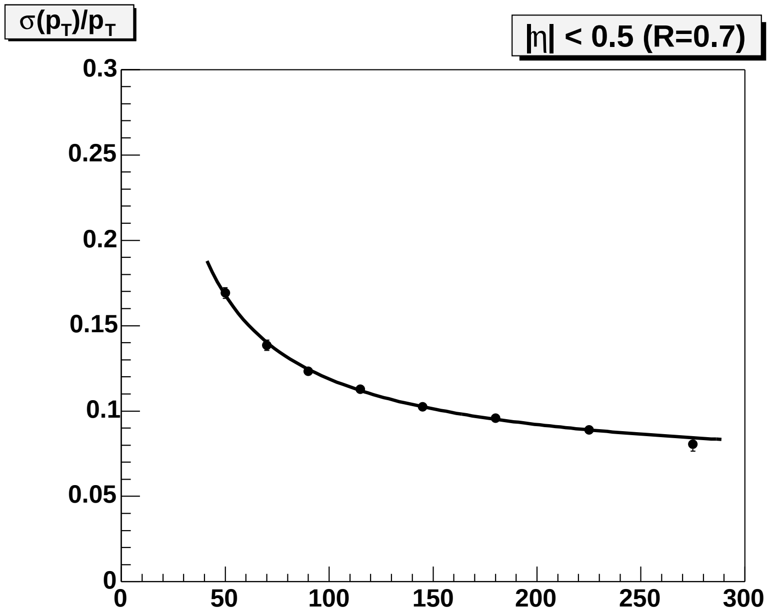
$$\mathcal{A} = \frac{|p_{T1} - p_{T2}|}{p_{T1} + p_{T2}}$$

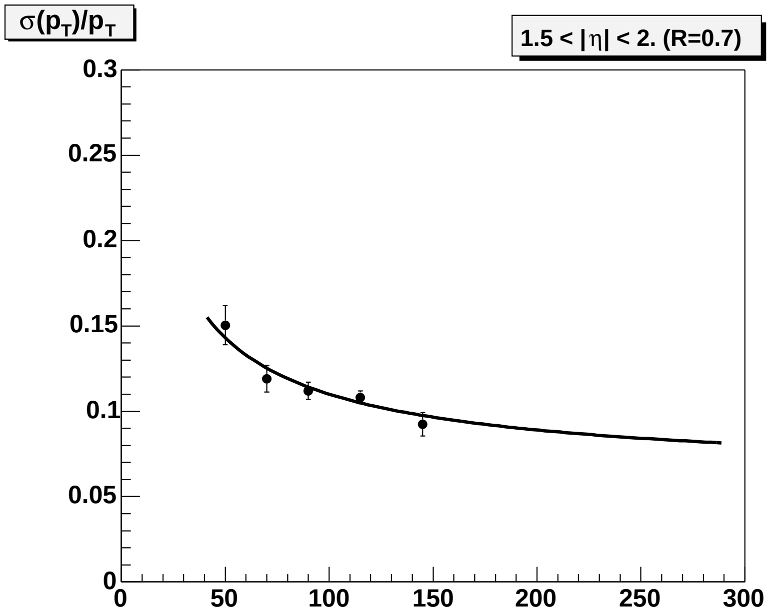
is directly related to p_T resolution

$$\frac{\sigma_{p_T}}{p_T} = \sqrt{2}\sigma_{\mathcal{A}}$$

- corrected for the soft radiation (additional jets below the 8 GeV reconstruction cut) and for jet imbalance on hadron level

Jet p_T resolution





$$\frac{\sigma_{p_T}}{p_T} = \sqrt{\frac{N^2}{p_T^2} + \frac{S^2}{p_T} + C^2}$$

N - noise term

S - sampling term

C - constant term

- larger value of resolution than in Run I
- reason is being investigated now
  - more dead material, larger noise
- we are working currently on determination of jet response from γ+jet sample

Summary

- Calibrating jet energies and understanding jet energy resolutions are essential parts of the DØ Run II program and is needed by most physics analyses
- Although in Run II, the calorimeter is the same as in Run I, jet energy scale and resolutions need to be derived from the very beginning due to new electronics and more dead material.
- Run II jet energy scale has been derived for data and MC for two different cones, $R = 0.5\,,\ 0.7$
  - currently, the error is 7% in data for central jets in the $30 - 250$ GeV region
  - the goal is to reach the understanding of the scale on the level of 2-3%
- Run II resolutions larger than in Run I
  - improvements are expected from advanced algorithms combining different subdetector information
- In future we expect further progress using: $Z \to b\bar{b}$, $W \to q\bar{q}$ in $t\bar{t}$ events